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SMALL-GABARIT ATOMIC POWER PLANT TES-3

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I. Introduction

In conformity with the plan for the development of atomic power industry in the Soviet Union the portable large-package atomic power plant with the pressurized-water reactor TES-3 (ТЭС-3) was put into experimental operation in I96I.

TES-3 is a demonstrative full-scale experimental prototype of low-power atomic power plant (APP) intended for operation in those regions of the USSR where it is economically advisable to use small atomic power plants.

It is of great significance for such APP that the construction work at the location of operation is minimum. In this respect TES-3 is APP produced at a plant as perfectly ready for operation. Practically all the equipment is arranged in four large packages and fits on four wheeled truck-trailers with heating bodies of a coach type. It reveals the possibility to employ TES-3 constructing no special buildings and to prepare the location of operation means in the main to build a biological shielding. TES-3 is mainly operated under stationary conditions without transporting to a new location of operation. Therefore a number of units (Diezel engine, transmissions, tracks etc.) linked with the running part of the power truck-trailers can be dismantledwhen arriving at the location of operation. In this case the frames of the power truck-trailers serve for usual base frames and the place which becomes free can be used as subsidiary rooms.

If necessary, the inter-trailers communications can be dismantled and the plant is transported to a new location of operation. Due to the overall weight and dimensions of power truck-trailers, they may be moved along railways. When moved, the reactor is cooled down by means of the air radiator placed in the reactor truck-trailer. It is possible to replace the burnt-up fuel assemblies under field conditions with the help of the overloaded container, by means of 25-ton autocrane, the reactor vessel top is not removed.

2. Description of the plant

TES-3 is situated in Obninsk at the territory of the World's First Atomic Power Plant. It is done with the account that the arrangement of the location, the mounting and employing of the plant perfectly correspond to its operation under field conditions. At the location of TES-3 operation (see Fig.I) there are power truck-trailers, the storehouse with spares and the prefabricated house with the switch board of the turbogenerator, the transformer for local needs and the sanitary inspection.

The power truck-trailer with the reactor and that with the other equipment of the primary circuit are located in a general trench 2.8 m deep, its overlap and walls are made of ferro-concrete and covered with the ground, the latter is the main biological shielding. The power truck-trailers with the turbogenerator and the control panel area are placed on the surface(Fig.2).

TES-3 is two-circuit steam-turbine set-up. The dividing into sections and reserving of the equipment are important for providing reliable operation of the plant under autonomous conditions. TES-3 is automazied; its power is automatically changed with changing a turbogenerator overload. 310

The Main Characteristics of the Plant:

Generator power	1500 kw
Reactor power	8800 kw
Pressure in the primary circuit	130 atm
Temperature at the reactor inlet	275°C
at the outlet	300°C
Parameters of the 2d circuit	
pressure in the steam generator	20 atm
temperature of steam superheat	280°C
pressure in the condenser	0.13 atm
Cooled water flow rate	1000 t/hr
Weight of the plant equipment	210 t
Weight of the transported shield is included	28.5 t
Weight of all power truck-trailers	310 t
Core life	250 days

3. Physics of the Reactor

The physical characteristics of TES-3 reactor were determined from the two-group theory taking into account the neutron multiplication at slowing-down and tested on three critical assemblies collected in series. In the first place the experiments were carried out on the assembly reproduced only approximately the core of TES-3. Further experiments were realized on two full-scale critical assemblies completely imitated TES-3. On one of the assemblies there were carried out "cold" experiments to make more precise the construction of the control elements and the uranium charge in the reactor. The last "hot" assembly could be heated nearly up to the temperature designed and thus the temperature effect may be studied.

<u>The initial reactivity</u> was obtained from $\frac{d\rho}{dh} = f(h)$. The critical height h was variated by changing the number of fuel assemblies (see Table I).

The critical mass of the reactor with the core designed, i.e. with II fuel assemblies removed, differs from the theoretical value by approximately 5 per cent. The reactivity of the cold clean core (0.II4) is also in a satisfactory agreement with the theoretical value (0.I23).

The temperature reactivity effect determines in most the safety of the reactor and convenience for its employing. Therefore it was paid a great attention in experiments on all the critical assemblies and the physical reactor start-up. The experiments showed a great dependence of the temperature effect on the absorbing rods available in the core and the removal of some fuel assemblies out of the core (Fig.3).

Efficiency of the control elements was studied for the rods of different materials, different construction and sizes when placing them inside the fuel assemblies and separate cells. The data on the control system selected are given in Table 2.

4. Shielding

The shielding of TES-3 consists of two parts: stationary mounted at the place of location and transportable.

The transportable shielding is made of lead and placed in the shield tank. The tank is filled with distillate or the solution of boric acid and provided with a cooling coil. The lead layer is I00-I90 mm thick. The water ($\sim$700mm) is an activation defence of the tank walls, coil and truck-trailer constructions. Before transporting the tank is emptied.

A peculiarity of TES-3 shielding is the use of lead as a heavy component because pure lead does not obtain a long-lived induced γ-activity and has no canning in the shield tank.

The other peculiarity of TES-3 shielding is the application of boric acid solution that leads to decreasing the activation of shielding materials and the constructions

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of the reactor power truck-trailers. Operation of TES-3 confirmed the efficiency of the measures indicated for decreasing the activation of γ-radiation. The calculations of the shield were realized in multi-group P_I-approximation with the given neutron group with $E \geq 1.5$ Mev and checked up by the measurements of neutron distributions in different variations of the shielding on a critical assembly.

In Table 3 there are levels of γ-radiation on a lateral surface of the reactor power truck-trailer measured at the initial period of TES-3 operation. Before measurements the reactor was operated at 3000 kw during 20 days. The safety shield tank was filled with distillate.

5. Operation of the Plant

Operation of TES-3 is realized to check up its efficiency under various conditions, to study the problems connected with designing and operating such plants that serves for finding the efficiency of using APP of small power in the national economy. Fig.4 represents the data determining the plant operation at different power levels. The results of an experiment on the reactor self-control are given in Fig.5. The plant start-up under autonomous conditions is realized by a starting electric generator of I50 kw supplied by a working Diezel engine of one of the power truck-trailers. The plant is operated under the various conditions: at constant power and sudden changes the turbogenerator load. Sometimes emergency shutdown was imitated when the units and systems of TES-3 were at first supplied from a storage battery and then from a diezel-generator.

Water operating conditions. For linking soluble oxygen and increasing pH up to the optimal value (9-IO) ammonia or hydrazine-hydrate were introduced into the water of the primary circuit. Hydrazine-hydrate proved to be more effective When introducing it the amount of oxygen in the primary circuit is 0.005 mg/l . Hydrazine - hydrate is also used in the secondary circuit, its use decreases oxygen concentration in the feed water up to 0.01-0.005 mg/l . To depress lead and steel corrosion in the shield tank pH in the solution of boric acid is maintained about 7 with the help of ammonia. Table 4 presents the data on water radiolysis in the shield tank when the concentration of boric acid is different as well as the reactor power.

6. Conclusion

The construction and operation of TES-3 showed that the experience of creating large-package portable plant with pressurized water reactor is rather successful. Long operation of TES-3 affirmed its reliability, good control and the convenience for maintenance of such plants.

Besides, TES-3 operation showed that there are possibilities of its further improvement, in particular, a more complete automation, increasing the core lifetime up to 2-3 years, transition to a natural coolant circulation at the reactor shutdown cooling etc .

A satisfactory agreement should be noted between the theoretical and actually obtained main parameters of the plant, that was favoured by a great number of the experiments carried out in the course of designing.

T a b l e I

Value of critical height h and $d\rho/dh$ for the core with a different number of fuel assemblies

Number of fuel assemblies a)	Diameter of the core	$\frac{D}{h}$	Critical height h (cm)		$d\rho/dh \cdot 10^2 \left(\frac{1}{cm}\right)$	
			experiment	calculation	experiment	calculation
3I	40.4	0.69	58.6	49.2	-	0.I73
32	4I.I	0.75	54.6	47.0	-	0.204
36	43.4	0.99	44.0	40.8	0.350	0.303
60	55.7	I.96	28.4	28.7	0.999	I.006
74	6I.9	2.46	25.I	26.3	-	-
79	63.9	2.64	24.2	25.8	I.36	I.344

a) There is no fuel assembly at the central cell

T a b l e 2

Efficiency of the control elements
$\left(\frac{\Delta k}{k} \cdot 10^3\right)$

Control elements	Material	t=20°C		t=280°C	
		experiment	calculation	experiment	calculation
Manual control rod	B_4C	6±0.I6	5.35	I2±0.3	8.97
Automatic control rod	Boric steel 2w.per cent of boron	I.5I±0.04	I.78	3.4±0.08	3.05
Safety rod	B_4C	5.7±0.I5	4.84	6.9±0.I8	5.72
"Soft"compensating system	Stainless steel	II4±2	90	-	-

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T a b l e 3

Dose rate (μ /sec) at lateral surface of reactor truck-trailer.

Time afetr shutdown (days)	0.I	0.5	I.0	I0	20	30
Experiment	30.2	6.92	3.02	0.I95	0.087	0.055
Calculation	33.2	I0.4	4.36	0.338	0.279	0.I87

T a b l e 4

Output of radiolytic gases in normal litres per hour per m^3 of solution.

Reactor power (Mw) / Concentration of boric acid (% weight)	3.3		5.5	
	H_2	0_2	H_2	0_2
0.04	0.35	0.2	0.68	0.42
I.7	I.45	0.8	3.0	I.45
3.5	3.7	I.8	5.6	2.55

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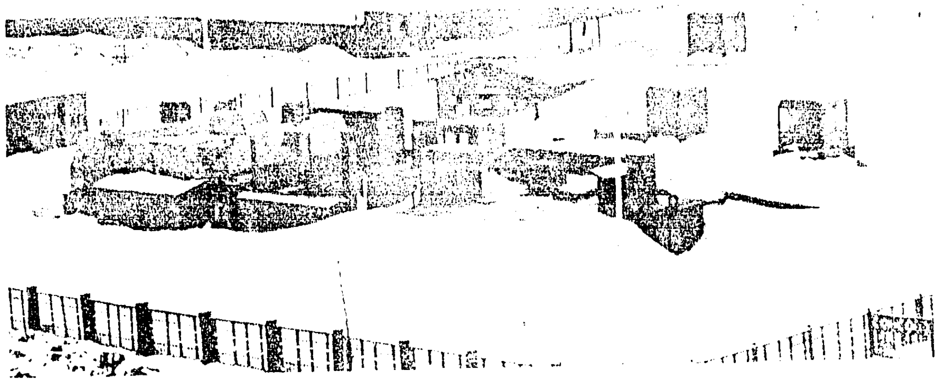

Fig.I. General view of TES-3 location of operation

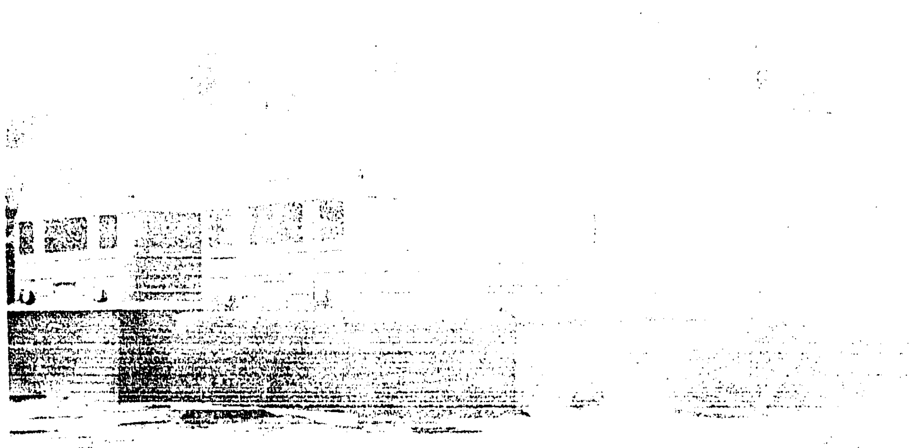

Fig.2. View on the truck-trailers with the control panel and turbogenerator. The trucks are covered to warm the trailers.

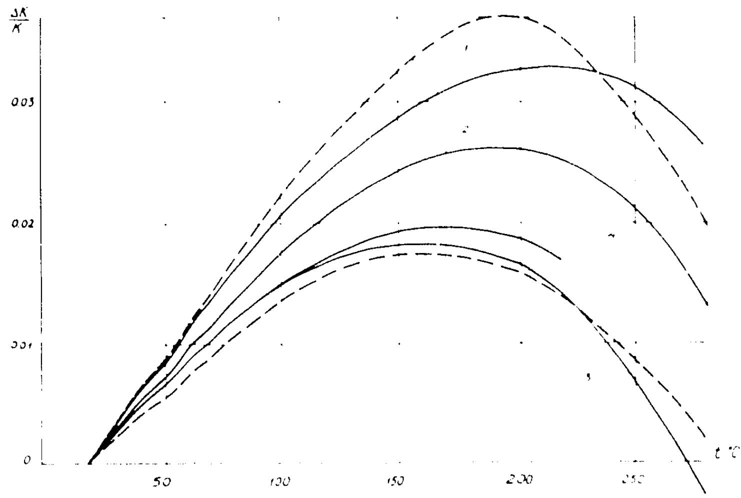

Fig.3. Reactor reactivity dependence (Δk/k) on the mean water temperature (t) in the reactor.

——————— Experiment

- - - - - - - - Calculation

I- Reactor with 74 fuel assemblies

2- The same reactor , two manual control rods in the core

3- The same reactor, six manual control rods in the core.

4- "Hot" critical assembly with 85 fuel assemblies.

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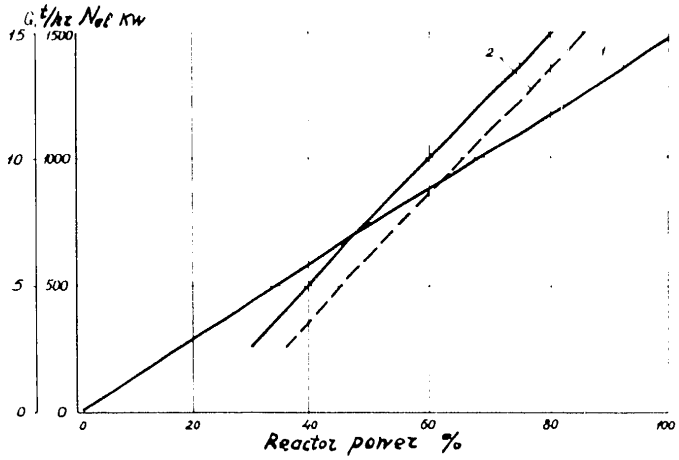

Fig. 4. Dependence of steam flow (G) and the generator power (N_{el}) on reactor power.

———————- Experiment

– – – – – – Calculation

I- Steam flow. 2- Generator power.

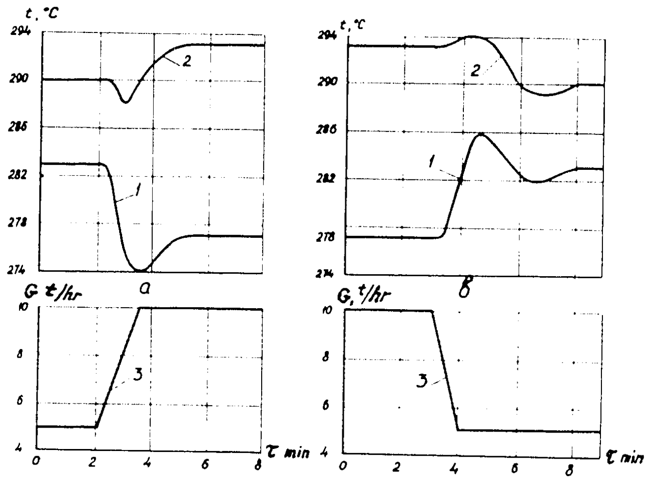

Fig.5. Reactor operation under self-control conditions
a)-at increasing of feed water flow per 5 t/hr
b)-at decreasing the feed water flow per 5 t/hr
I-Water temperature at the reactor inlet
2-Water temperature at the reactor outlet
3-Feed water flow.

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